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DEPARTMENT OF DEFENCE

ROYAL AUSTRALIAN AIR FORCE

AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

EDINBURGH, SOUTH AUSTRALIA

TECHNICAL NOTE AERO NO 81

DETERMINATION OF THE PITCH AND ROLL GAIN LIMITS FOR THE F-111C AUTOMATIC FLIGHT CONTROL SYSTEM

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A manual Automatic Flight Control System (AFCS) gains changer was designed into the flight-test F-111C, A8-132, for F-111C flight flutter trials. The system was designed to be adjusted in flight to enable a worst case aircraft flutter response to be evaluated during flutter testing. Technical Note Aero No 81 tasked Aircraft Research and Development Unit to conduct flight tests to determine the range of the self adaptive AFCS gains that occur normally within the F-111C flight envelope and to determine the highest gain values that could be set before the aircraft demonstrated dynamic instability.

The flight-test results showed that the self-adaptive pitch and roll gain values were higher than indicated by General Dynamics. The results further showed that the aircraft response varied with feedback gain setting and that at airspeed above 400 KCAS the gains could be set to values to induce neutral dynamic response in the test aircraft. A gains envelope was determined for F-111C flight flutter testing at a level 10% below the neutral stability setting. (Keywords: Australia; pitch gain; roll gain).

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AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

DETERMINATION OF THE PITCH AND ROLL

GAIN LIMITS FOR THE F-111C

AUTOMATIC FLIGHT CONTROL SYSTEM

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ARDU File Reference: 2660/81/Tech

TECHNICAL NOTE AERO 81

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SUMMARY

A manual Automatic Flight Control System (AFCS) gains changer was designed into the flight-test F-111C, A8-132, for F-111C flight flutter trials. The system was designed to be adjusted in flight to enable a worst case aircraft flutter response to be evaluated during flutter testing. Technical Note Aero No 81 tasked Aircraft Research and Development Unit to conduct flight tests to determine the range of the self adaptive AFCS gains that occur normally within the F-111C flight envelope and to determine the highest gain values that could be set before the aircraft demonstrated dynamic instability.

The flight-test results showed that the self-adaptive pitch and roll gain values were higher than indicated by General Dynamics. The results further showed that the aircraft response varied with feedback gain setting and that at airspeed above 400 KCAS the gains could be set to values to induce neutral dynamic response in the test aircraft. A gains envelope was determined for F-111C flight flutter testing at a level 10% below the neutral stability setting.

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TECHNICAL NOTE AERO 81

DETERMINATION OF THE PITCH AND ROLL GAIN LIMITS FOR THE F-111C AUTOMATIC FLIGHT CONTROL SYSTEM

1. INTRODUCTION

1.1 A manual Automatic Flight Control System (AFCS) gains changer was designed into the flight-test F-111C, A8-132, for F-111C flight flutter trials. The gains system was designed to be adjusted in flight to enable a worst case aircraft flutter response to be evaluated as the response of the aircraft varies with AFCS gain setting. The first part of the task was to determine the ranges of the AFCS self-adaptive pitch and roll gain that occur normally within the F-111C flight envelope. This was an essential pre-requisite for operation of the manual pitch and roll gain control systems. The second stage was to conduct functional tests on the manual gain system and to determine the highest gain values that could be set for flight flutter testing before the aircraft demonstrated dynamic instability. The results of both sets of tests are documented in this report.

2. CONDITIONS RELEVANT TO THE TESTS

2.1 System Description

2.1.1 The AFCS has been provided for the F-111C to provide well-behaved aircraft handling characteristics at all flight conditions and good response to random gusts. A Stability Augmentation System (SAS) is included for pitch, roll and yaw to provide well-behaved aircraft dynamic response throughout the aircraft flight envelope. Signals from gyros and accelerometers are used to compute commands to the damper servos to enable the aircraft to exhibit little or no overshoot characteristics. The Command Augmentation System (CAS) is used in both pitch and roll so that variations in aircraft response to stick displacement will be minimized as flight conditions change. A stick position transducer transmits a rate command signal to the damper servo, through a summing junction. The other input to the summing junction is a rate feedback term from a gyro and the error signal fed to the damper servo is the difference between the commanded roll rate (stick induced) and actual roll rate. The error signal of both the pitch and roll systems is gain adjusted before being input to the damper servo. The system is shown in schematic form at Figure 2.1.

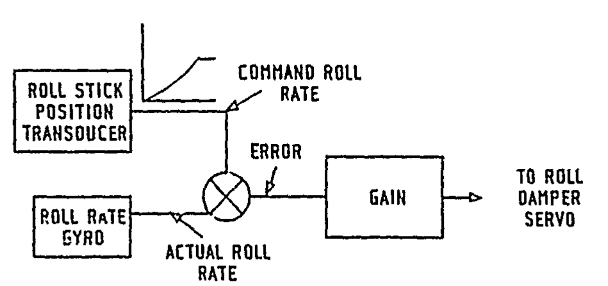


Figure 2.1 - F111C Roll Control System Schematic

2.1.2 The pitch command to the pitch damper servos and the roll command to the roll damper servos are gain adjusted by self-adaptive gain changers. The gains are adjusted by circuits within the AFCS based upon the frequency and magnitude of oscillations that exist on the rate gyros. The required value of the gain is dependent on the flight regime of the aircraft. As the natural response of the F-111C is very sluggish at low dynamic pressures, high gains are needed for low speed - high altitude flight, conversely, low gains are required for high speed - low altitude flight, as the F-111C is very sensitive at high dynamic pressures. As the gain value is increased, a low amplitude oscillation will appear on the horizontal stabilizer. The gain changer mechanism will drive to keep the gains as high as possible to secure optimum aircraft response, while remaining low enough to prevent the pilot detecting the stabilizer oscillation. Values of predicted gains for various flight conditions were documented in Reference A and are included as Annex A. A more complete description of the F-111C AFCS can be found in both Reference A and the F-111C Flight Manual, Reference B.

2.2 Test Aircraft. A8-132 was used for all tests. The test aircraft was fitted with the RAAF Airborne Flight-Test Recording and Analysis System for the trial to enable test data to be recorded on board and telemetered to the Aircraft Research and Development Unit telemetry ground station.

2.2.1 Configuration. The test aircraft was configured with pivot pylons on stations 3, 4, 5 and 6.

2.2.2 Test Aircraft Modifications. A8-132 has been extensively instrumented under Test Schedule 1650 and has extensive internal wiring modifications. External modifications were limited to the addition of two wing tip and two aft fuselage camera fairings. Modifications to the cockpit included the installation of a Data Acquisition System control panel, switches and indicators for manual control of the AFCS gain system, and a flutter exciter store (FES) control panel. The AFCS gains systems have been modified to enable both pitch and roll gain values to be set and varied manually by the test aircrew. A description of the modifications may be found in ARDU reports KAIV003 and KAIV031.

2.2.3 Cockpit Modifications. Cockpit modifications have been made to enable the crew to exercise manual control over the AFCS gains. The controls are located on a panel which replaced the TFR 'E' scope, and consist of an enable switch, a drive switch (+/-) and a tracking LED for each of the axes. The enable switches have two positions, ENABLE and OFF; the drive switches allow the crew member to increase or decrease the gain with the system in manual, and the tracking LEDs show that the manual gain tracking sub-system is keeping pace with the system gains in the adaptive mode (thus preventing discrepancies between adaptive and manual gains on engagement). One indicator per axis displays gain. The indication is presented as 'percent' but a correction factor must be applied to derive the true gain value. For convenience, gain values stated in this report are 'indicated percent'. The correction factor is shown in Annex B.

2.3 Telemetry. Flight-testing was monitored through the telemetry ground station. Parameters available for monitoring are shown in the Instrumentation Record (Annex C).

3. TESTS MADE

3.1 Flight tests were made in both the manual and self adaptive gains mode as described in the following paragraphs.

3.2 Self-Adaptive Mode Tests. The tests conducted in the self-adaptive mode consisted of recording the values of pitch and roll gains during stabilized level flight at specific test points.

3.3 Manual Gain Mode Tests. The flight tests in the manual gain mode consisted of increasing pitch and roll gain (separately and then together) at stabilized test conditions until a small control disturbance caused the aircraft damping to decrease to a point where 'neutral' dynamic stability was encountered.

3.4 Test Matrix. The test flights were performed in accordance with the test matrix at Annex D.

4. TEST METHODOLOGY

4.1 Self-Adaptive Mode. The aircraft was stabilized at the test point for two minutes with constant power lever settings, 7 degrees incidence, minimum of flight control activity and no atmospheric turbulence. The flight crew monitored the gains indicators and recorded the maximum gain value. The aircraft was then subjected to rapid and continuous longitudinal, lateral and directional control inputs and the lowest gain level was recorded by the test crew.

4.2 Manual Gain Mode. The aircraft gains were driven well below the maximum steady-state value, as determined from the self-adaptive gain tests, by the application of rapid lateral and longitudinal control inputs. The gains were manually driven upwards at 5 percent intervals from the starting value. A small, but sharp control input (longitudinal for pitch gain and lateral for roll gain) was made to disturb the aircraft. The aircraft response was measured by the ground station staff to determine response frequency and damping ratio. The gains were increased until maximum gain (100%) or neutral damping ($\zeta = 0$) was achieved.

4.3 Data Reduction. The results from the self-adaptive mode tests were directly compared with the information contained in Reference A. Analytical data reduction was only performed on flight-test data obtained from manual mode flight tests Serial Nos 1 to 14 of Annex D to determine plots of damping ratio versus gain value. The data reduction technique involved measurement of the aircraft transient peak ratio (TPR) of the pitch rate response due to pilot input. The damping ratio of the reponse was then calculated using the known relationship between TPR and damping ratio. The detailed data reduction plan is documented at Annex E.

5. RESULTS OF TESTS AND DISCUSSIONS

5.1 Self-Adaptive Mode Results. The results of the self-adaptive mode gain tests shown at Annex F in both tabular and graphical form. The listed results represent the maximum recorded gain values for each test condition were between five and 10 percent higher than expected for both the pitch and roll system. The pitch gain system was generally more stable than the roll system and followed the expected gain theory of high values for low speed and low values for high speed. The roll gain results were not readily repeatable airframe buffet.

5.2 Manual Mode Results. The results of manual mode gain tests for each test altitude are given in the following paragraphs.

5.2.1 Tests at 30,000 ft. With the gains in the self-adaptive mode, the pitch and roll gains drifted to 100%. Manual gains were engaged at 90% setting with no adverse effect on aircraft response or systems. Gains were increased manually in 5% increments to 100%. Pitch damping was virtually constant throughout. Roll damping decreased slightly with speed with gains set at 100%, except for 325 and 350 KCAS test points where the damping actually increased.

5.2.2 Tests at 25,000 ft. The test points were 300, 350, 380 and 410 KCAS. Manual gains were engaged at least 10% lower than those demonstrated in Adaptive Mode tests, para 5.2. Gains were again increased incrementally as in para 5.2.1, except that the increments were reduced to 2% as the damping ratio approached 0.1. Roll damping decreased marginally with increasing roll gain; however, gains could be set at 100% for all test points with only a mild oscillatory response. The pitch response showed decreasing damping with increasing gain, except for the $\Lambda = 26^{0}$ 300 KCAS case, where the damping ratio actually increased with gain. A minimum damping ratio of 0.06 was measured for the 410 KCAS case. The pitch gain versus damping ratio curve is shown at Annex G-1.

5.2.3 Tests at 20,000 ft. The test points were 300, 350, 400 amd 450 KCAS. The manual gains were engaged at least 10% lower than the adaptive mode test values. Gains were again increased incrementally as in para 5.2.1 tests. The roll rate response again showed a small change with increasing gain. Some small, well-damped oscillations did occur with the higher gain settings; however, gains could be set at 100% for all test points. The pitch response showed decreasing damping, for all test points, with increasing gain. This was especially apparent for the 450 KCAS test. The resultant undampened pitch oscillation at maximum gain was in the 2 to 3 Hz frequency range. Plots of the pitch rate damping ratio versus pitch gain are shown at Annex G-2.

5.2.4 Tests at 15,000 ft. The test points were 425, 450, 475 and 500 KCAS. Manual gains were engaged at a 10% lower value than that established as maximum gain during adaptive gains testing and gains were increased incrementally as in para 5.2.1. Roll damping decreased with increasing gain, however gains could be set at 100% for all test points, with the resulting aircraft motions being deadbeat (lower values), or with minor roll oscillations (higher value). With pitch gain, damping of aircraft motions decreased markedly with increased gain until a point was reached where a small stick input resulted in an undamped or slightly divergent aircraft motion. The motion was a pitch oscillation of about 2 Hz.

5.2.5 Tests at 10,000 ft. The test points were 300, 400 and 450 KCAS. Manual gains were engaged at values at least 10% below the previously determined adaptive gain values. The gain values were also increased incrementally as in para 5.2.1 tests. The roll gain values again exhibited a decrease in damping ratio as gain was increased, however the minimum damping ratio did not preclude a gain setting of 100% for speeds up to 450 KCAS. The pitch rate response showed a decreasing damping ratio for increasing gain for all test airspeeds. The pitch oscillations were approximately 2 to 3 Hz and tended towards neutral dynamic stability at high gain values. The relationship between pitch rate damping ratio and pitch gain value is shown at Annex G-3.

5.2.6 Tests at 3000 ft. The test points were from 425 to 625 KCAS in 25 knot increments. Manual gains were engaged at values 10% lower than those established during adaptive gains testing. Gains were increased incrementally as per para 5.1.2. Roll damping decreased with increasing gain, however gains could be set at 100% for all test points up to 625 KCAS, with resultant motions being deadbeat (lower values) or minor damped lateral oscillations at the higher gain settings. With pitch gain, damping of the aircraft motions decreased markedly with increasing gain until a point was reached where a small stick input resulted in a neutrally damped or slightly divergent aircraft motion. The motion was a pitch oscillation of about 2 Hz, +/- 0.2 'g' and +/- 0.25 alpha.

6. CONCLUSIONS

6.1 The analysis of the flight-test results of the two types of F-111C gain mode tests are given in the following paragraphs.

6.2 Self-Adaptive Gain Mode Tests. The test results showed that the pitch and roll gain settings were higher than expected and provide a guide to the highest gain values that occur naturally in the AFCS. Before the manual gain system is enabled, the adaptive gains must be driven (by rapid control stick inputs) to a value well below those established by flight test.

6.3 Manual Gain Mode Tests. The tests showed that the aircraft response to disturbance depended on gain and generally followed simple state feedback theory. When gain was increased at airspeeds of 400 KCAS and above, a point was reached where the aircraft exhibited 'neutral stability' characterisitics, ie, oscillated without decay. The suggested gains settings, shown in Annex H, have been determined by the application of a 10% buffer below the neutral stability setting.

7. RECOMMENDATIONS

7.1 The following recommendations are made regarding operations of the F-111C with the AFCS gains set in the manual made.

a. A gain setting of 100% may be used for both the pitch and roll AFCS gain systems at airspeed values at or below 350 KIAS; and

b. The gain boundaries defined at Annex H should be applied for manual gain flight tests for airspeeds above 350 KIAS.

8. REFERENCES

A. GD/FW FZM-12-14178, Automatic Flight Control Trouble Shooting Data, 12 April 1982.

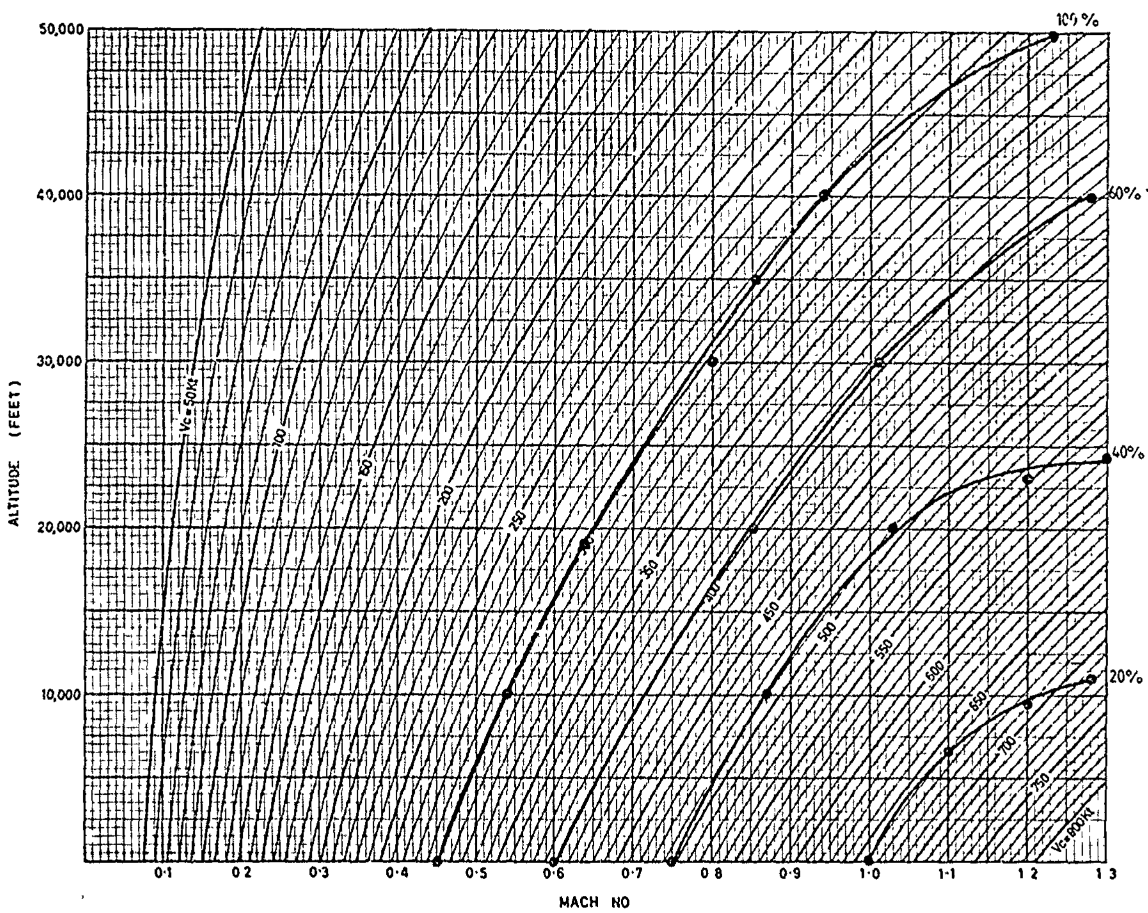
B. DI(AF)AAP 7214.003-1, F-111C Flight Manual.

9. PROJECT PERSONNEL

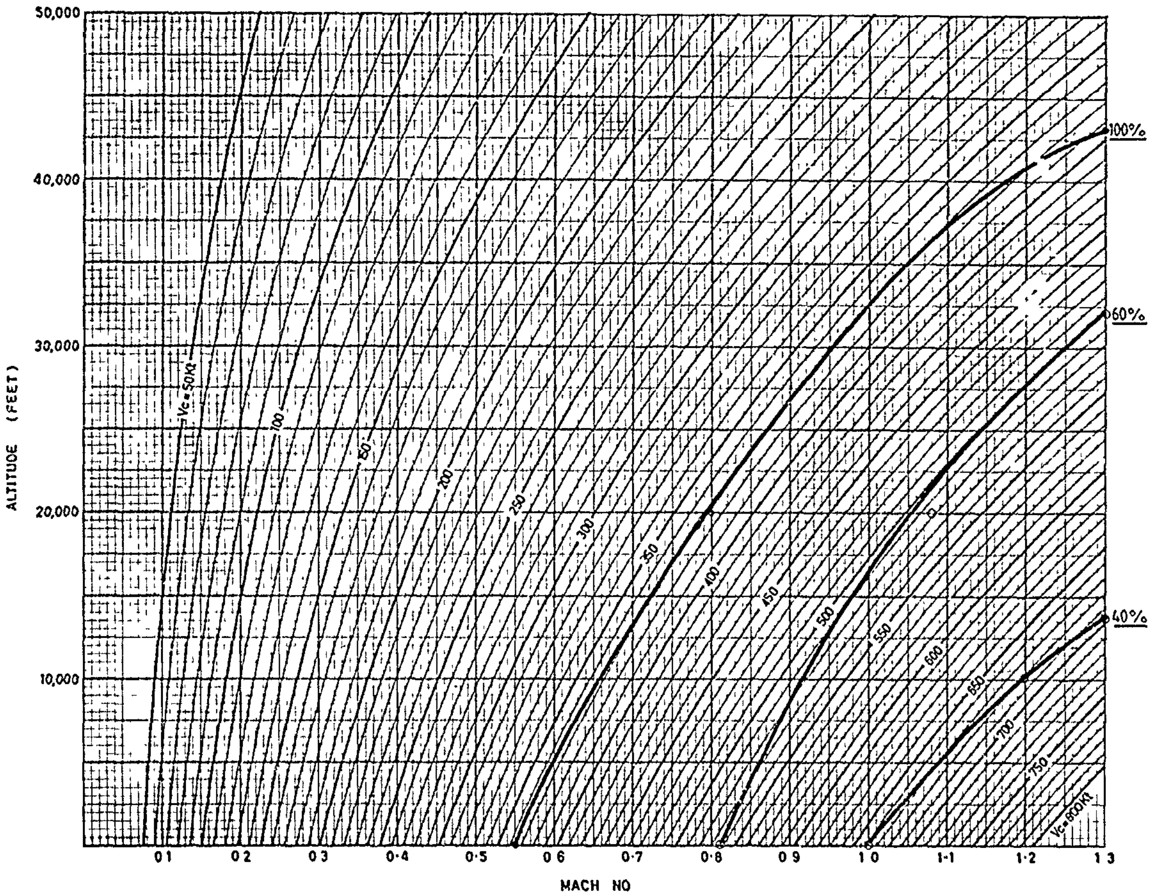
Project Officers: Wing Commander R.A. Howard
Squadron Leader T.W. Poynton BE (Syd) MSc

GAINS VS AIRSPEED - THEORETICAL

PREDICTED PITCH GAINS

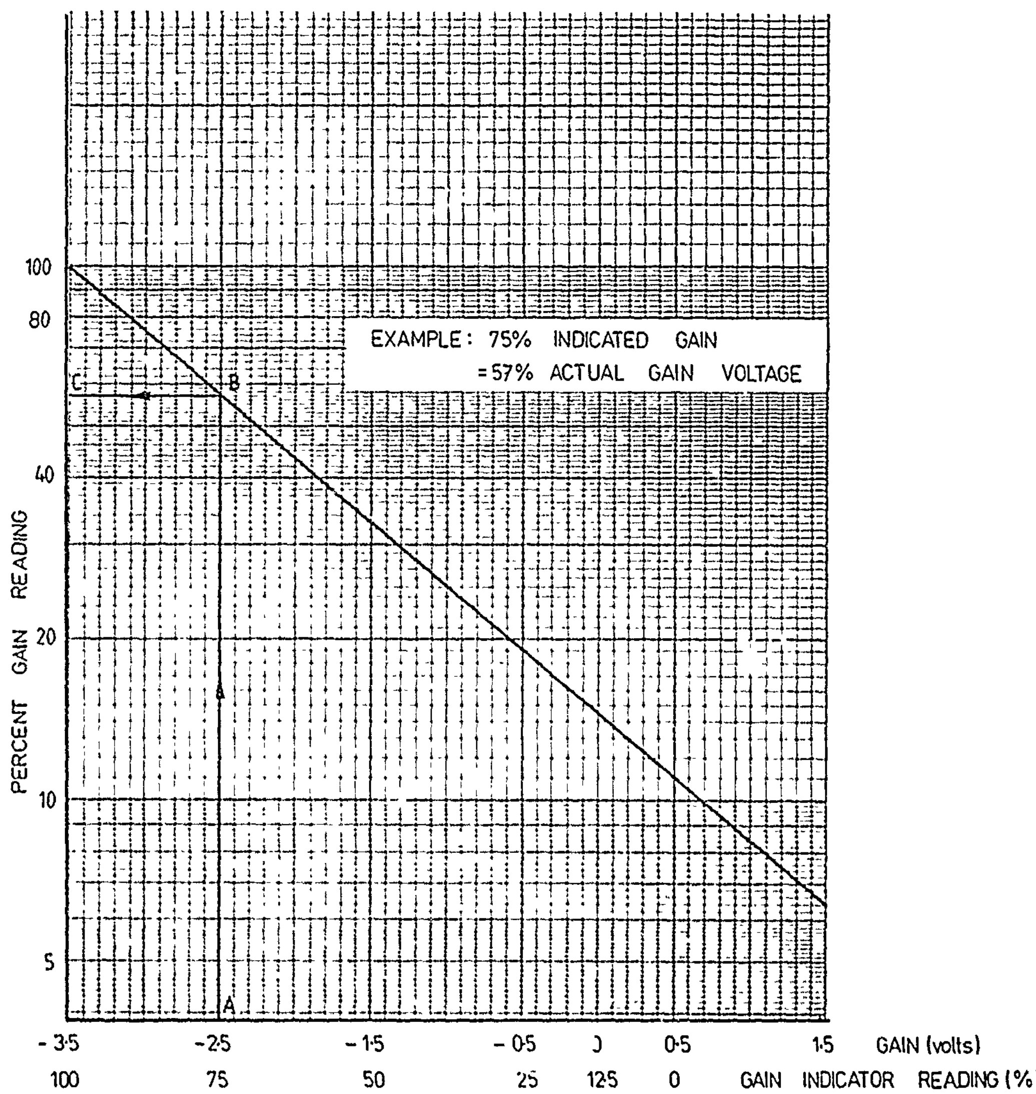


PREDICTED ROLL GAINS

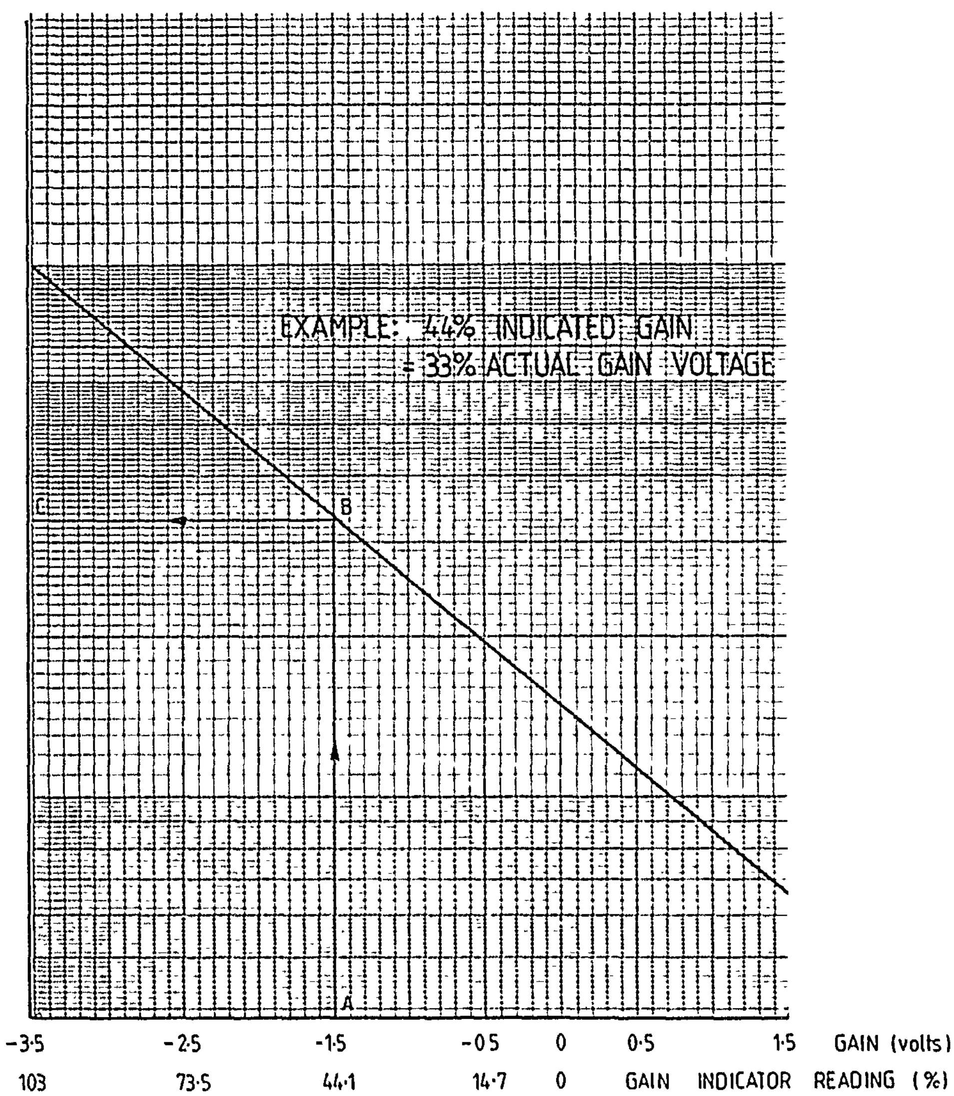


GAINS VS PERCENT GRAPHS

PITCH GAIN INDICATOR VOLTAGE



ROLL GAIN INDICATOR VOLTAGE



MEASURAND LISTING

DATA WORD No.	AETRAS ADDR. (HEX)	MEASURAND No.	RECORDER INPUT CONNECTOR	PARAMETER	DATA WORD No.	AETRAS ADDR. (HEX)	MEASURAND No.	RECORDER INPUT CONNECTOR	PARAMETER
01	00	BI-114	P105/A	PITCH GAIN A	51	31	SI-080	P207/A	THERMAL STORE TEMP. 1
02	01	BI-115	" B	" " B	52	32	SI-081	" B	" " " 2
03	02	BI-116	" C	" " C	53	33	SI-082	" C	" " " 3
04	03	BI-117	" D	ROLL GAIN A	54	34	SI-083	" D	" " " 4
05	04	BI-118	" E	" " B	55	35	SI-084	" E	" " " 5
06	05	BI-119	" F	" " C	56	36	SI-085	" F	" " " 6
07	06	BI-170	" G	ACCN VERT C of G	57	37	SI-086	" G	" " " 7
08	07	BI-171	" H	" LAT C of G	58	38	SI-087	" H	" " " 8
09	08	RI-049	" J	BATV TM +VE CAL	59	40	BI-031	" S	NBTU ALPHA TEMP.
10	09	RI-050	" K	" " 0 "	60	3A	BI-028	" K	" ACCN, X-AXIS (LONG)
11	0A	RI-051	" L	" " -VE "	61	3B	BI-027	" L	" " Z-AXIS (VERT)
12	0B	RI-052	" M	" " TEMP	62	43	BI-032	" V	" BETA TEMP
13	0C	RI-053	" N	" " +15V RAIL	63	3D	BI-029	" N	" ACCN ROLL
14	0D	RI-054	" P	" " -15V RAIL	64	3E	SI-088	" P	THERMAL STORE TEMP 9
15	0E	RI-055	" R	" " BATTERY VOLTS	65	3F	BI-178	" R	YAW ANG ACCN. C OF G.
16	0F	BI-045	" S	WING SWEEP POS'N LVDT	66	60	BI-023	DATA BUS	NBTU ANGLE OF ATTACK
17	10	RI-046	" T	BATV CH 1 TM	67	61	BI-025	" "	" " " SIP: SLIP
18	11	RI-047	" U	" CH 2 "	68	62	BI-039	" "	PORT STAB SYNCRO
19	12	RI-048	" V	" CH 3 "	69	63	BI-040	" "	STBD " "
20	13	SI-074	" W	FEM VANE ANGLE STA 6	70	64	BI-041	" "	RUDDER POS'N "
21	14	SI-077	" X	STBD VANE FORCE STA 6	71	65	BI-043	" "	PORT SPOILER " OUTBOARD
22	15	SI-078	" Y	PORT VANE FORCE STA 6	72	66	BI-044	" "	STBD " " "
23	16	SI-071	" Z	FEM Y-AXIS ACCN STA 6	73	67	BI-053	" "	STICK POS'N " LONG
24	17	SI-072	" a	FEM X-AXIS ACCN STA 6	74	68	BI-054	" "	" " " LAT
25	18	SI-073	" b	FEM VANE ANGLE STA 3	75	69	BI-055	" "	RUDDER PEDAL POS'N SYNCRO
26	19	SI-075	" c	STBD VANE FORCE STA 3	76	50	BI-012	" "	DIGIOZ STATIC PRESS ABS
27	1A	SI-076	" d	PORT VANE FORCE STA 3	77	4A			
28	1B	SI-069	" e	FEM Y-AXIS ACCN STA 3	78	51	BI-013	" "	DIGIOZ TOTAL PRESS ABS
29	1C	SI-070	" f	FEM Z-AXIS ACCN STA3	79	70	BI-191	" "	CADS ALT FINE
30	1D	CI-004	" g	ACCN WING TIP PORT FWD	80	52	BI-018	" "	DIGIOZ TRUE MACH NO.
31	1E	CI-005	" h	" " " STBD "	91	71	BI-190	" "	CADS ALT COARSE
32	1F	CI-006	" i	" " " PORT AFT	82	53	BI-014	" "	DIGIOZ TRUE AIRSPEED
33	20	CI-007	" j	" " " STBD "	83	72	BI-195	" "	CADS MACK NO. COARSE
34	21	CI-002	" k	ACCN STABILIZER PORT	84	54	BI-016	" "	DIGIOZ PRESS ALTITUDE
35	22	CI-003	" m	" " STBD	85	73	BI-196	" "	CADS MACH NO. FINE
36	23	BI-172	" n	ACCN LONG C of G	86	55	BI-021	" "	DIGIOZ AMBIENT TEMP
37	24	BI-140	" p	PITCH GAIN STATUS	87	75	BI-184	" "	CADS AIRSPEED FINE
38	25	BI-141	" q	ROLL GAIN STATUS	88	76	BI-187	" "	CADS ANGLE OF ATTACK
39	26	BI-173	" r	PITCH GYRO C OF G	89	77	BI-188	" "	CADS ANGLE OF SIDESLIP
40	27	BI-174	" s	ROLL " "	90	7D	BI-214	" "	ADI PITCH ANGLE
41	28	BI-175	" t	YAW " "	91	7E	BI-215	" "	ADI BANK ANGLE
42	29	BI-056	" u	STICK FORCE LONG	92	42	BI-047	P207/U	WING SWEEP STATUS >47
43	2A	BI-197	" v	TOTAL TEMP INDIC TAP	93	39	BI-176	P207/J	PITCH ANGLE ACCN C OF G
44	2B	BI-169	" w	ACCN LAT FEB	94	3C	BI-177	P207/M	ROLL ANGLE ACCN C OF G
45	2C	CI-001	" x	" LAT FIN	95	41	BI-046	P207/T	WING SWEEP STATUS >45
46	2D	BI-168	" y	" VERT FEB	96	56		DATA BUS	DIGIOZ DQ1 TEMP
47	2E	BI-166	" z	" " MODULE	97	57		" "	DIGIOZ DQ2 TEMP
48	2F	BI-057	" AA	STICK FORCE LAT	98	2A			
49	30	BI-167	" BB	ACCN LAT MODULE	99	FE			AETRAS TM SYNC.
50	7C	BI-006	DATA BUS	CAL SYNCHRO O/P	100	FF			AETRAS TM & RECORDER SYNC

TEST MATRIX

SELF-ADAPTIVE MODE TESTS

Serial	Altitude (ft)	Airspeed (KCAS)	Remarks
1	3,000	250, 300, 350, 400, 450, 475, 500, 525, 550, 575, 600, 625	Stabilized Level Flight
2	15,000	250, 300, 350, 400, 425, 450, 475, 500	—
3	30,000	250, 275, 300, 325, 350	—

MANUAL MODE TESTS

Serial	Altitude (ft)	Airspeed (KCAS)	Remarks
1 - 4	25,000	300, 350, 380, 410	Analytic Test Required Telemetry Used
5 - 8	20,000	300, 350, 400, 450	Analytic Test Required Telemetry Used
9 - 14	10,000	350, 380, 400, 450, 500, 550	Analytic Test Required Telemetry Used
15 - 19	30,000	250, 275, 300, 325, 350	No Telemetry Used
20 - 27	15,000	250, 300, 350, 400, 425, 450, 475, 500	No Telemetry Used
38 - 39	3,000	250, 300, 350, 400, 450, 475, 500, 525, 550, 575, 600, 625	No Telemetry Used

DATA REDUCTION OF AIRCRAFT OSCILLATORY RESPONSE

1. The disturbed motion of an aircraft is either oscillatory or non oscillatory. For an oscillatory response, the aircraft handling requirements are usually stated in terms of undamped natural frequency (ω) and damping ratio (ζ). The following paragraphs detail a technique for determining the actual aircraft ω and ζ values from flight-test data.

2. Test Data. Time response histories of both pitch rate and roll rate were recorded both via the ground telemetry station and on the on-board digital data recorder. A typical aircraft rate response of the F-111C aircraft to the pilots input is shown at figure 1.

3. Data Reduction. The transient peak ratio (TPR) of the response was calculated using the relationship.

$$TPR = \frac{DA_{m=r}}{DA_{m=r}} \text{ for } r>o \qquad \text{(refer to figure 1)}$$

The aircraft damped natural frequency was calculated using the relationship:

$$\omega_d = \frac{2\pi}{T}$$

The damping ratio (ζ) of each response was determined using the known relation between TPR and ζ, shown at figure 2. The undampened natural frequency (ω) was then determined from:

$$\omega = \frac{\omega_d}{(1 - \zeta^2)^{1/2}}$$

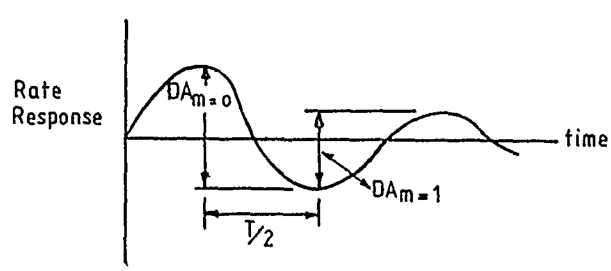


Figure 1

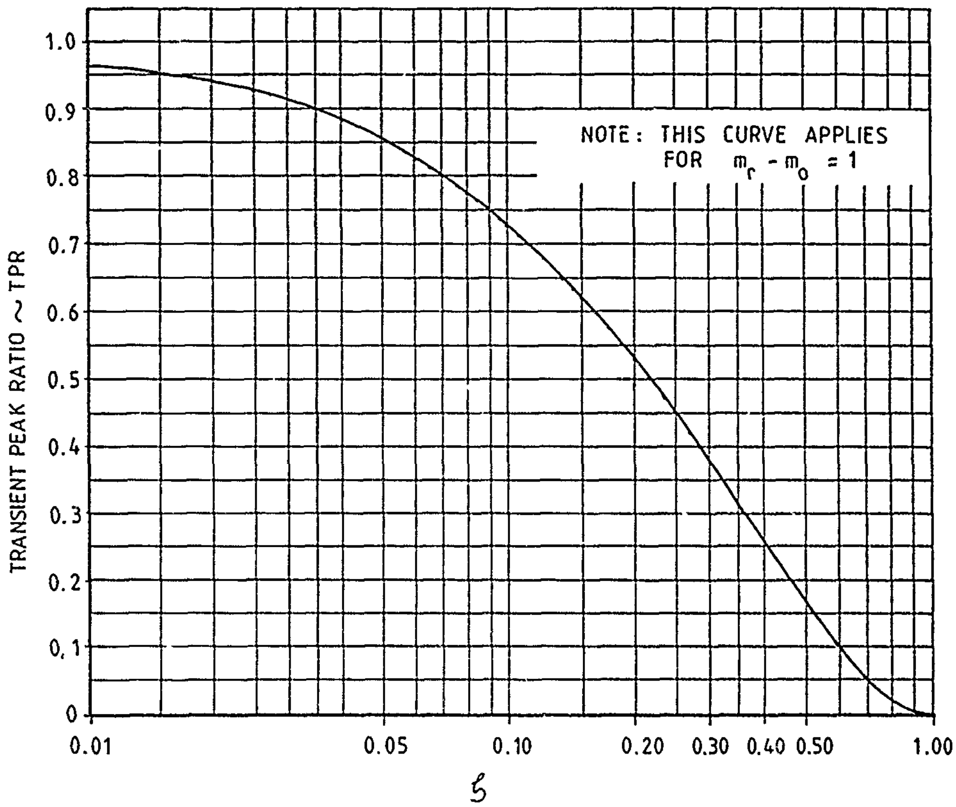


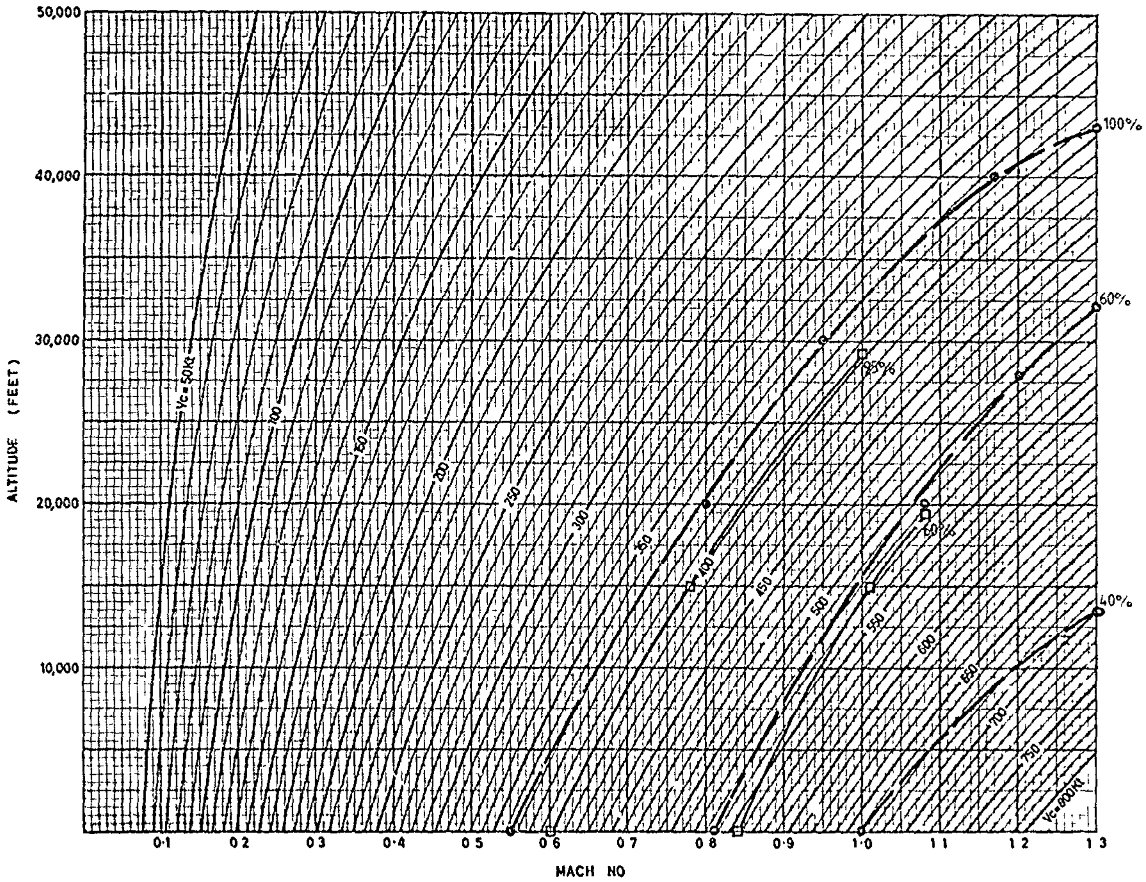
Figure 2-Transient Peak Ratio Vs ζ

ADAPTIVE GAIN TEST RESULTS

STABILIZED FLIGHT

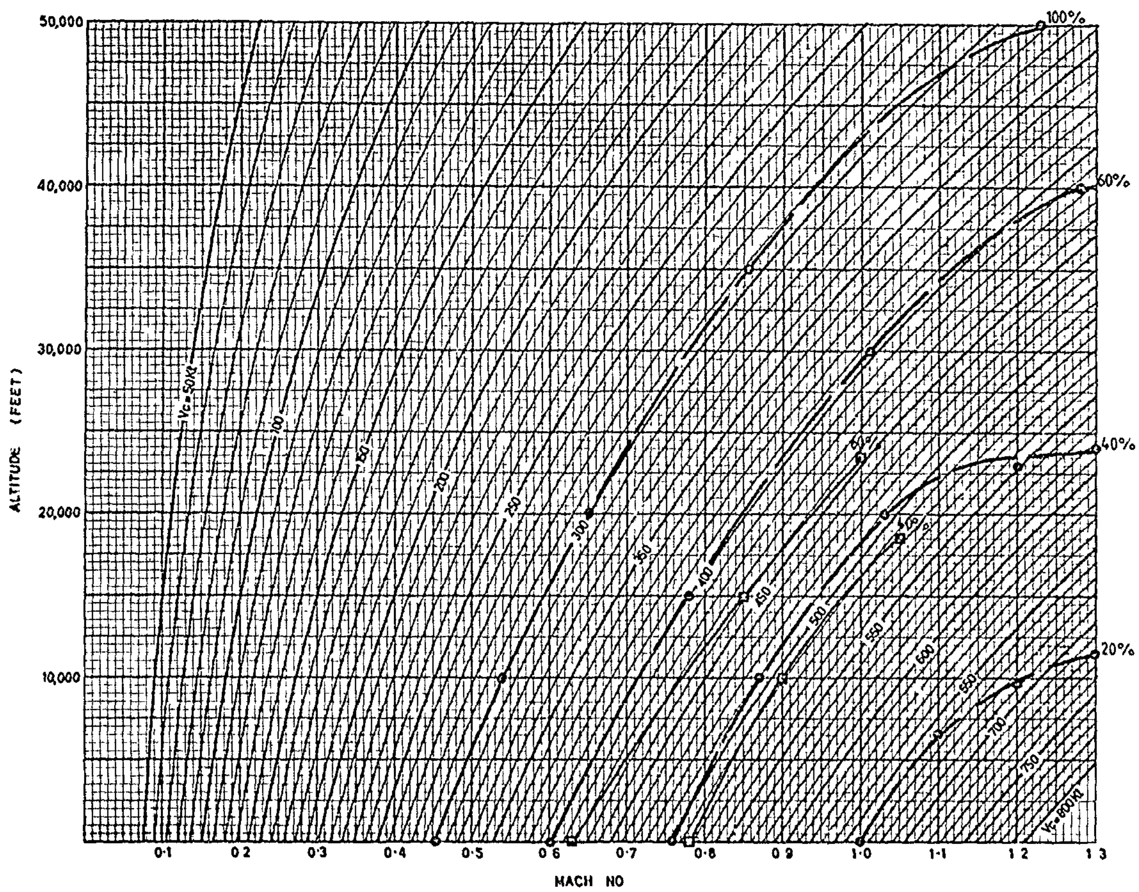
Serial	Airspeed (CAS) (KTS)	Altitude (FT)	Pitch Gain (%)	Roll Gain (%)
1	250	3000	100	100
2	300	3000	100	100
3	350	3000	80	100
4	400	3000	65	95
5	450	3000	53	87
6	475	3000	48	80
7	500	3000	42	73
8	525	3000	38	65
9	550	3000	33	60
10	575	3000	30	56
11	600	3000	28	53
12	625	3000	25	50
13	250	F150	100	100
14	300	F150	100	100
15	350	F150	90	100
16	400	F150	72	95
17	425	F150	56	86
18	450	F150	56	86
19	475	F150	50	80
20	500	F150	44	75
21	250	F300	100	100
22	275	F300	100	100
23	300	F300	100	100
24	325	F300	95	100
25	350	F300	86	100

ROLL GAINS



50,000
40,000
30,000
20,000
10,000
ALTITUDE (FEET)
0·1
0 2
0 3
0·4
0 5
0 6
0 7
0 8
0·9
1·0
1 1
1 2
1 3
MACH NO
100%
60%
40%
Vc=50Kt
100
150
200
250
300
350
400
450
500
550
600
650
700
750

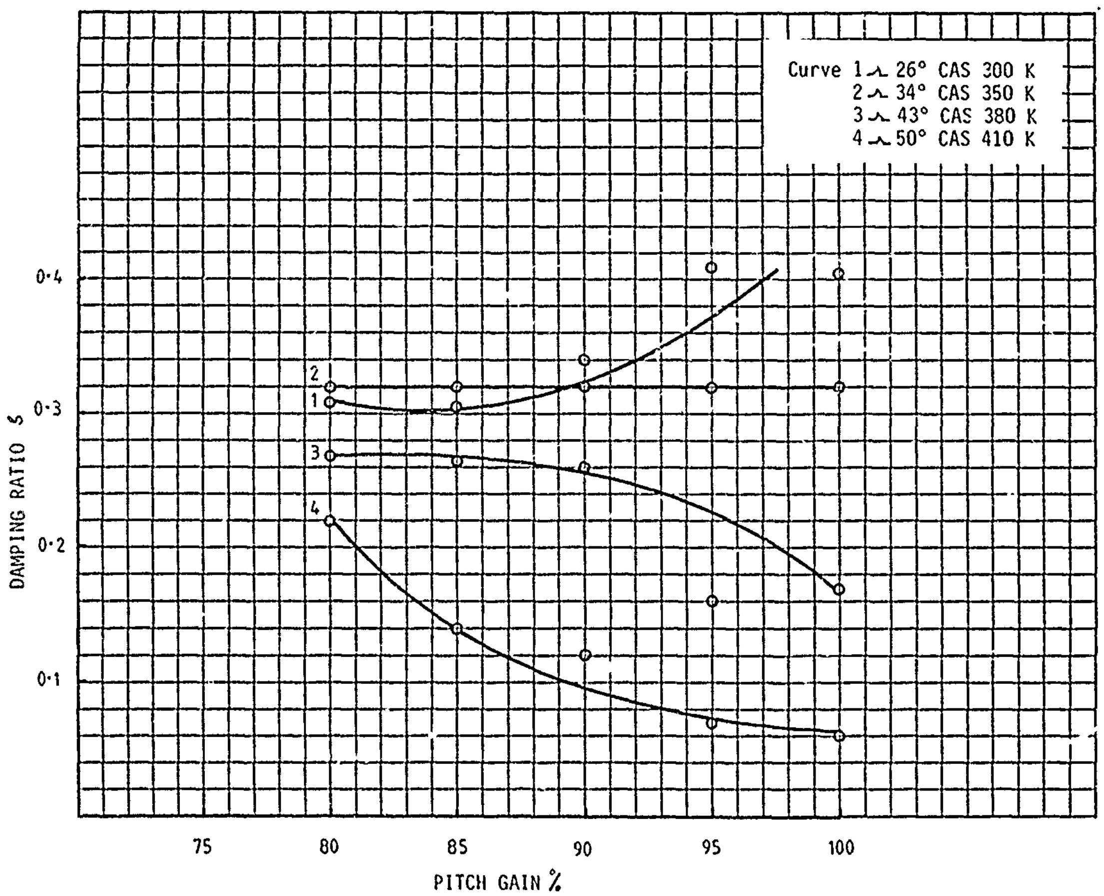
PITCH GAINS



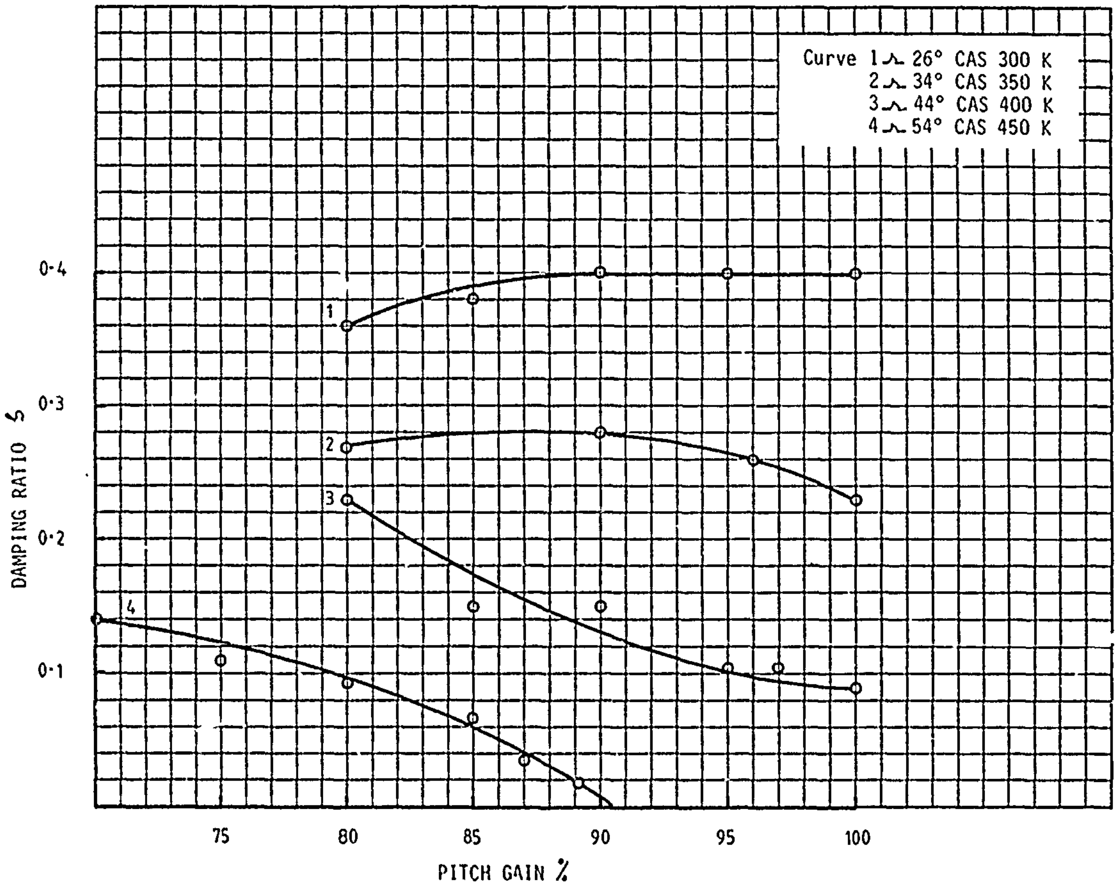
50,000
40,000
30,000
20,000
10,000
ALTITUDE (FEET)
Vc=50KT
100
150
200
250
300
350
400
450
500
550
600
650
700
750
Vc=800KT
100%
60%
40%
20%
0·1
0·2
0·3
0·4
0·5
0·6
0·7
0·8
0·9
1·0
1·1
1·2
1·3
MACH NO

MANUAL MODE TEST RESULTS

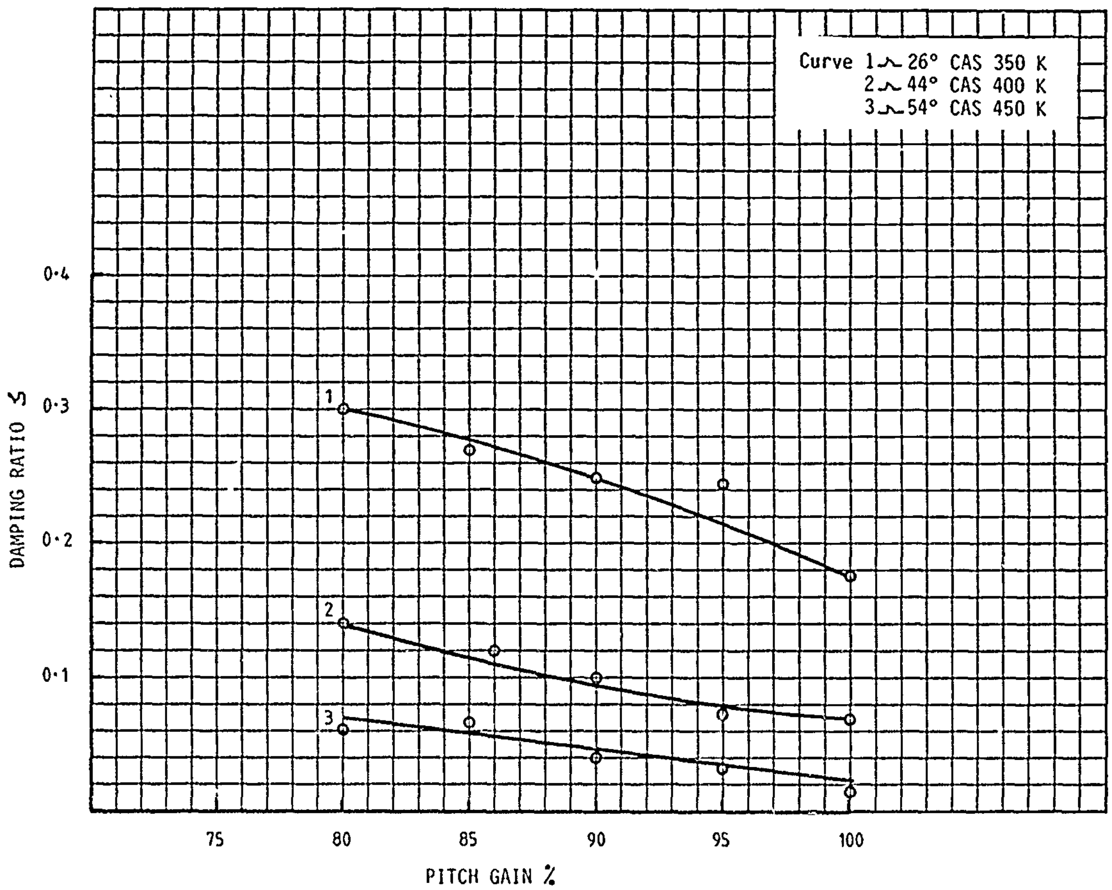
PITCH GAIN VS DAMPING FOR 25,000 FT



PITCH GAIN VS DAMPING FOR 20,000 FT

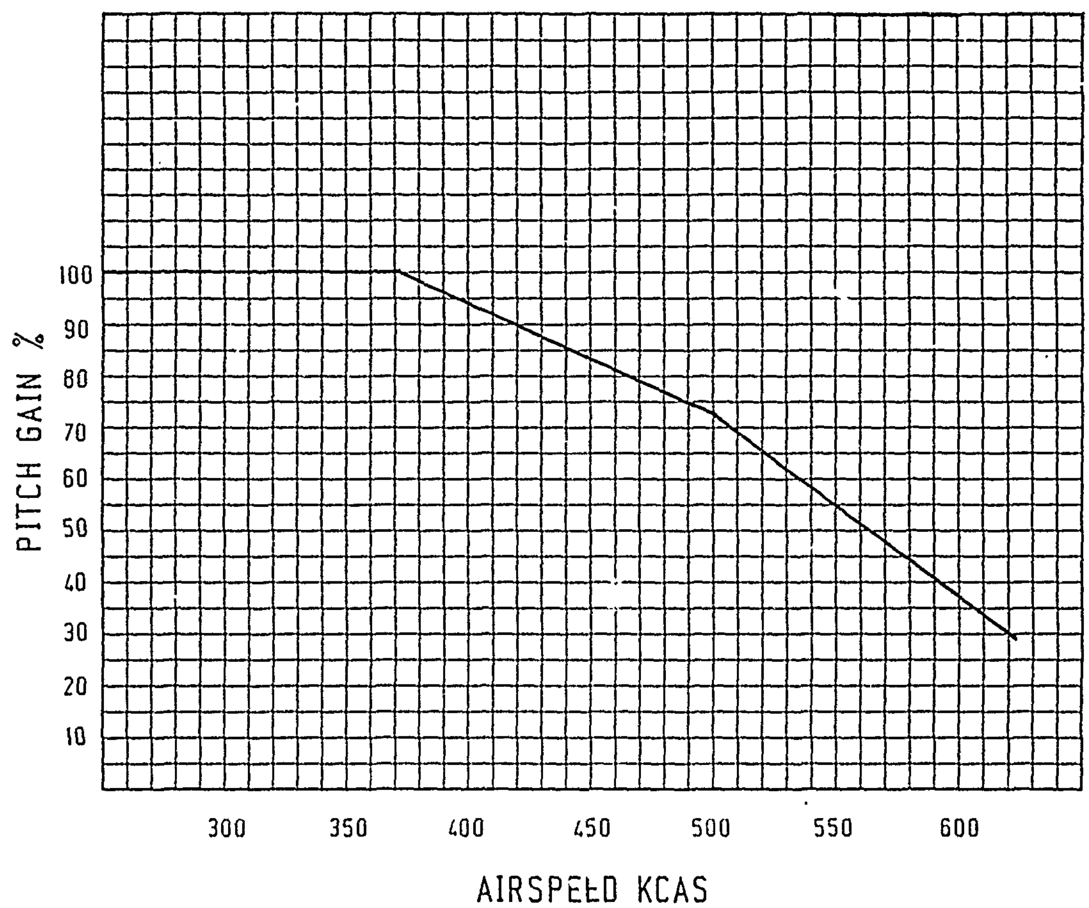


PITCH GAIN VS DAMPING FOR 10,000 FT

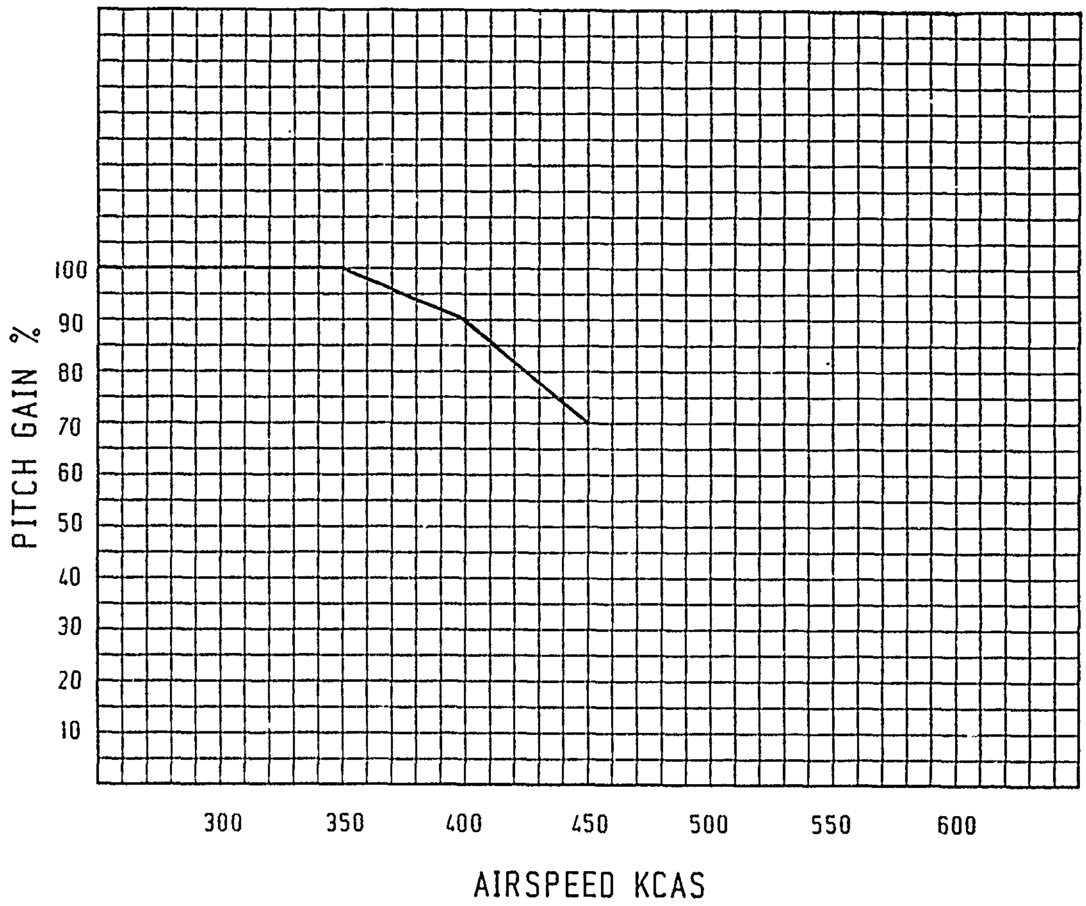


GAINS FLIGHT ENVELOPE

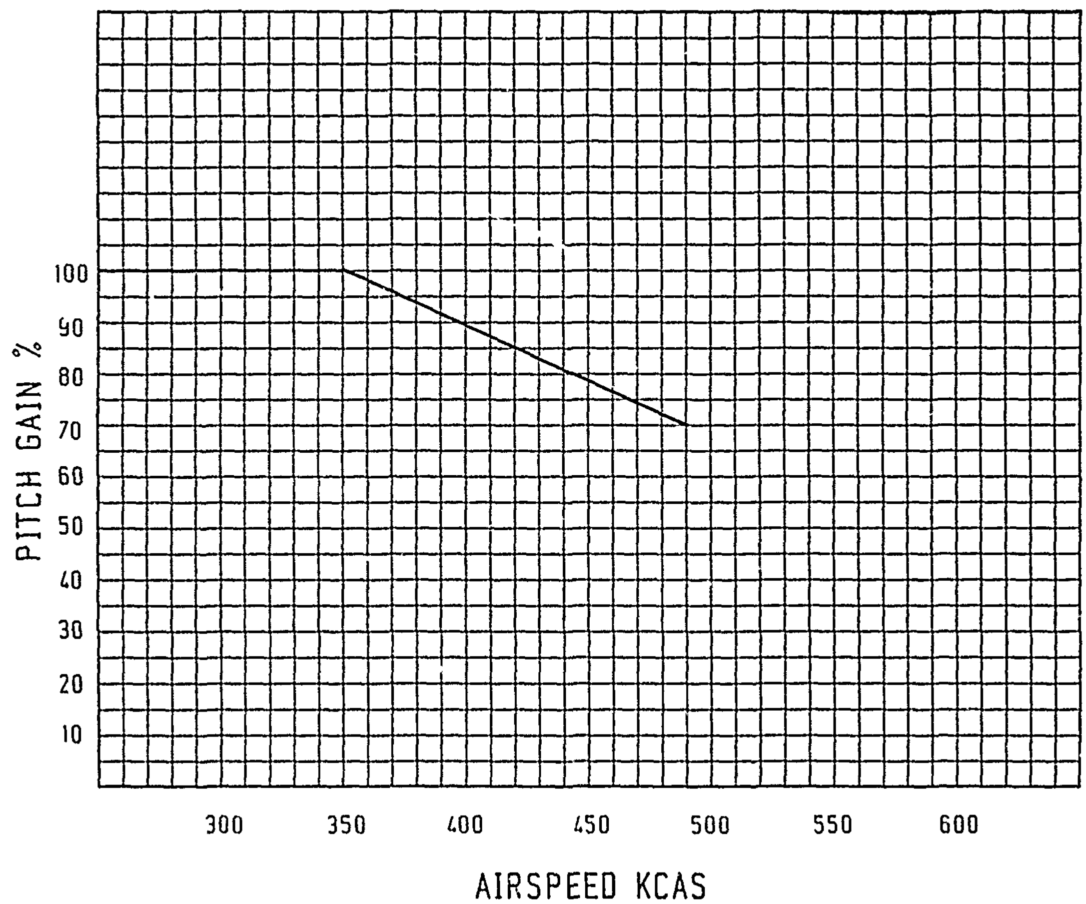
MANUAL PITCH GAIN LIMITS FOR HEIGHT OF 3,000 FT



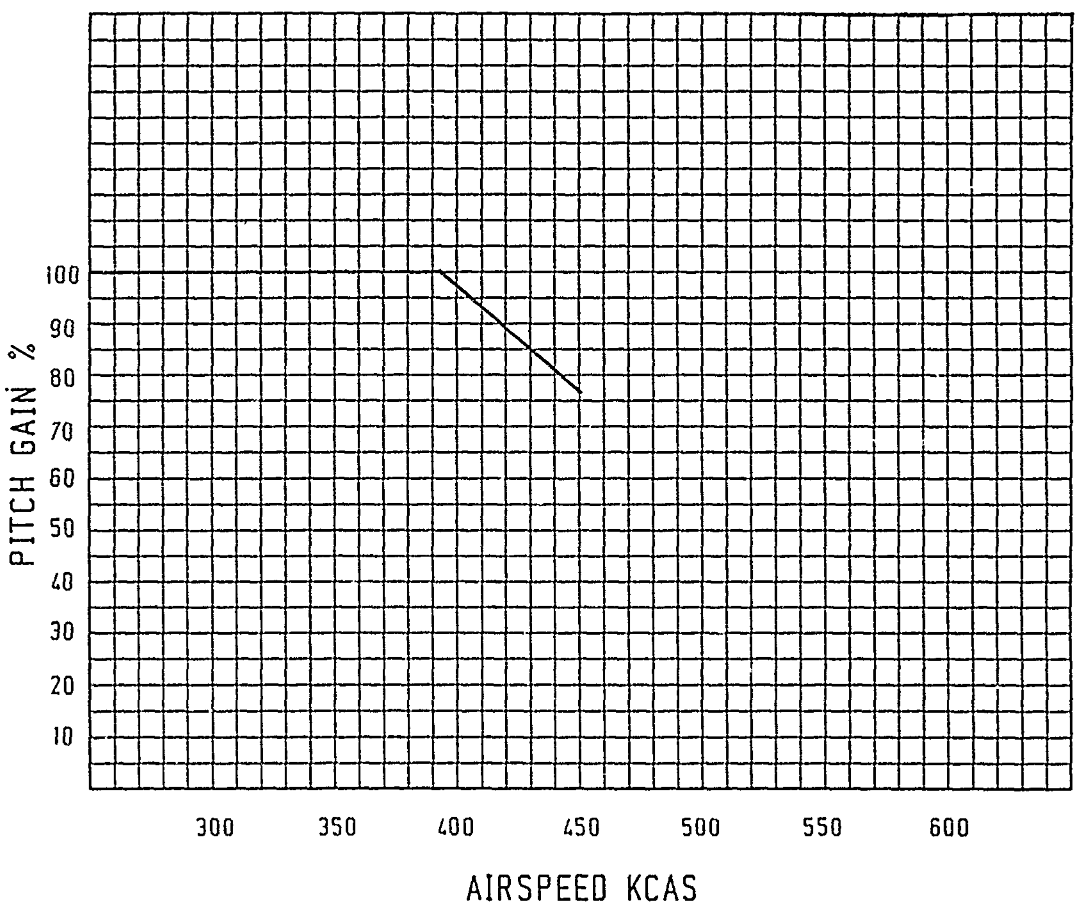
MANUAL PITCH GAIN LIMITS FOR HEIGHT OF 10,000 FT



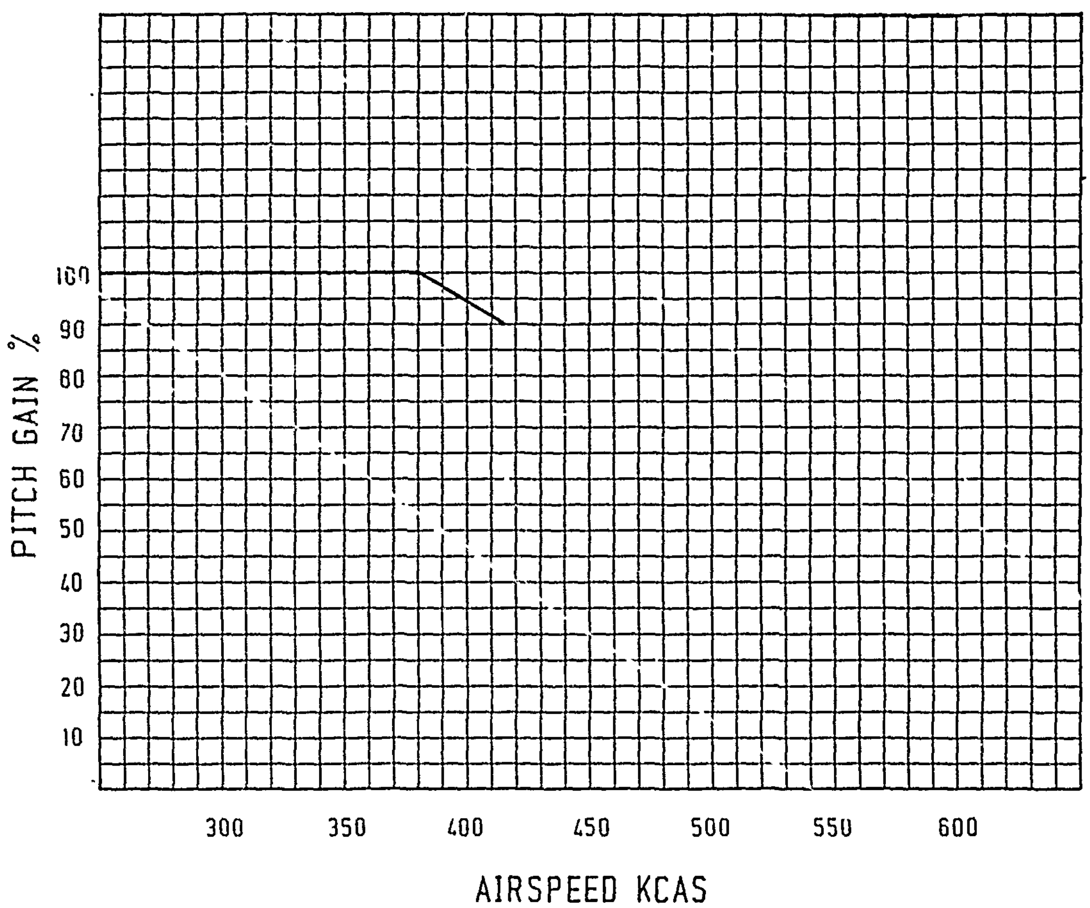
MANUAL PITCH GAIN LIMITS FOR HEIGHT OF 15,000 FT



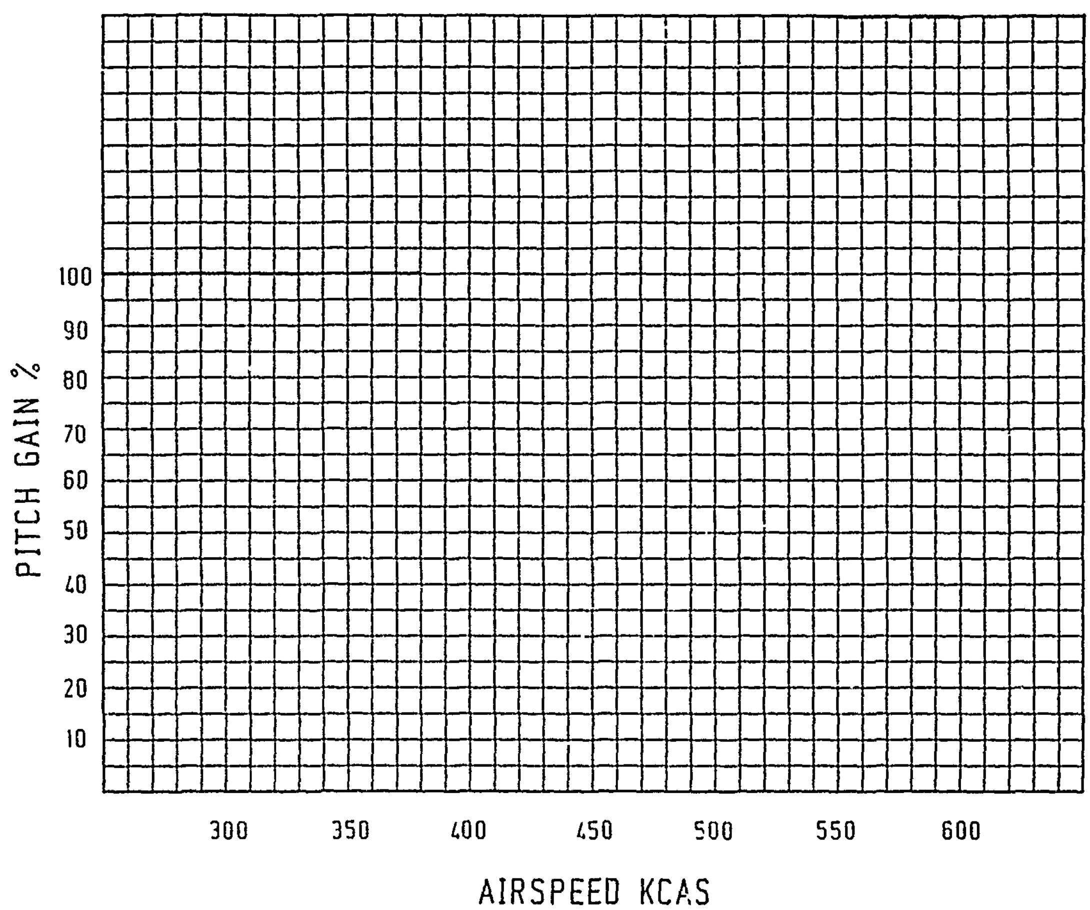
MANUAL PITCH GAIN LIMITS FOR HEIGHT OF 20,000 FT



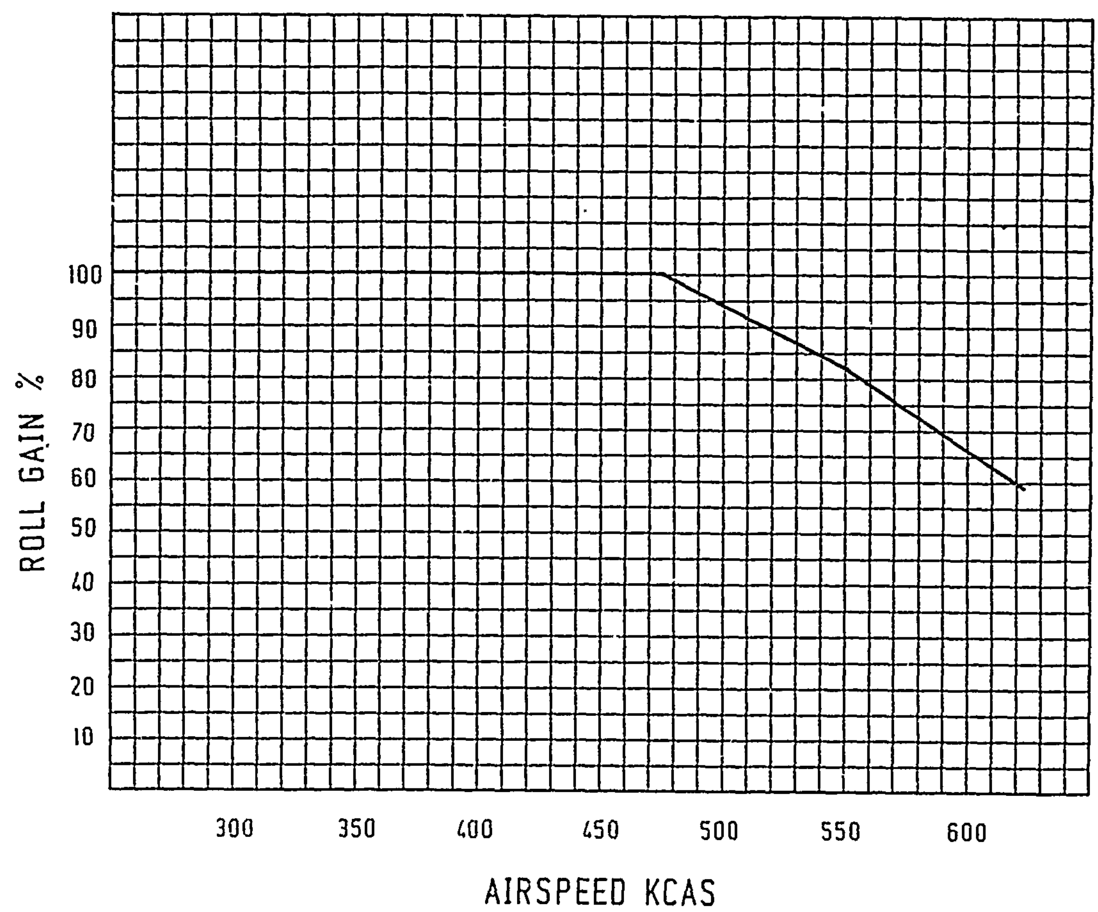
MANUAL PITCH GAIN LIMITS FOR HEIGHT OF 25,000 FT



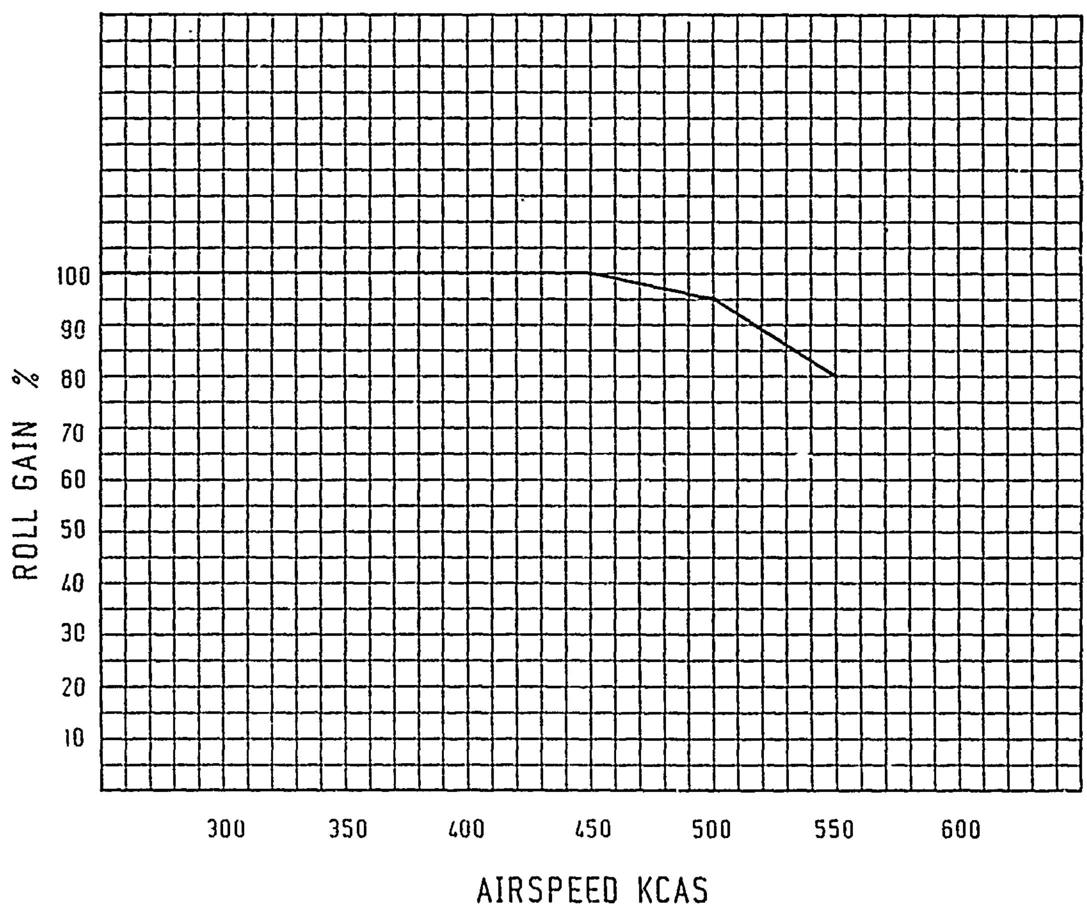
MANUAL PITCH GAIN LIMITS FOR HEIGHT OF 30,000 FT



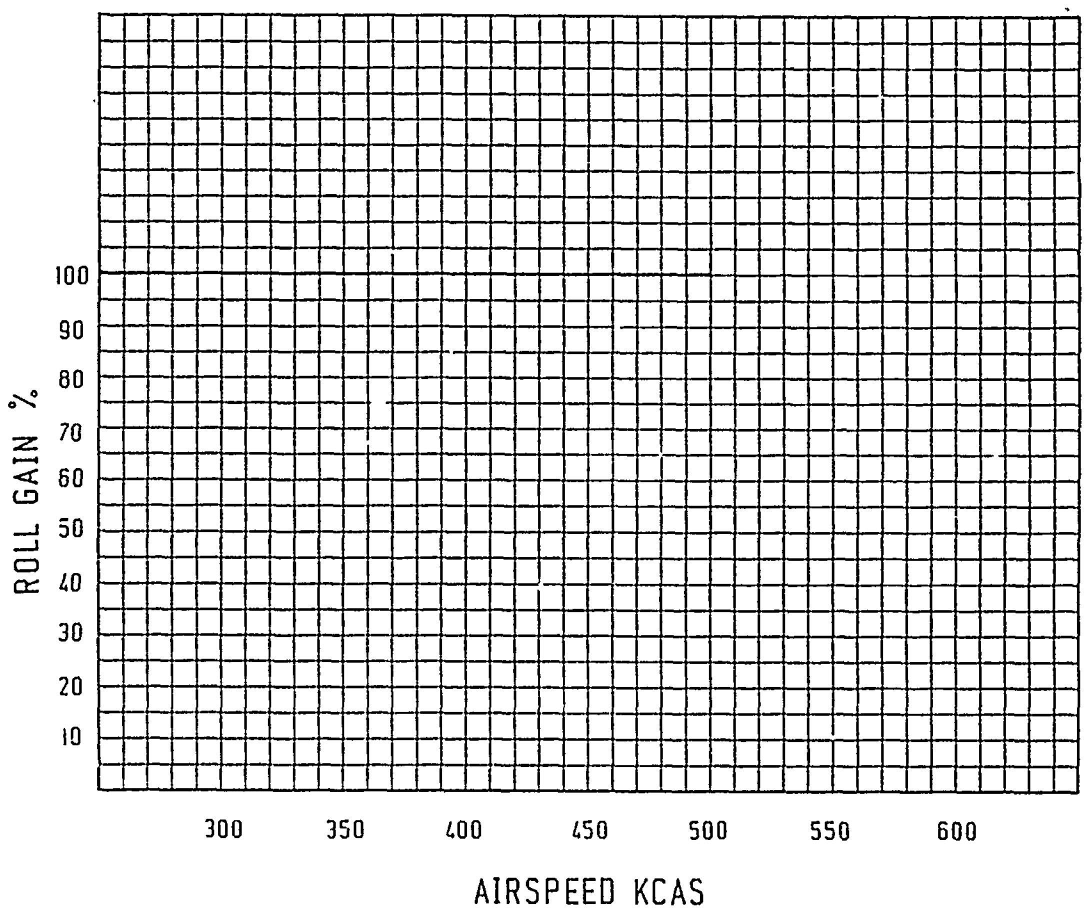
MANUAL ROLL GAIN LIMITS FOR HEIGHT OF 3,000 FT



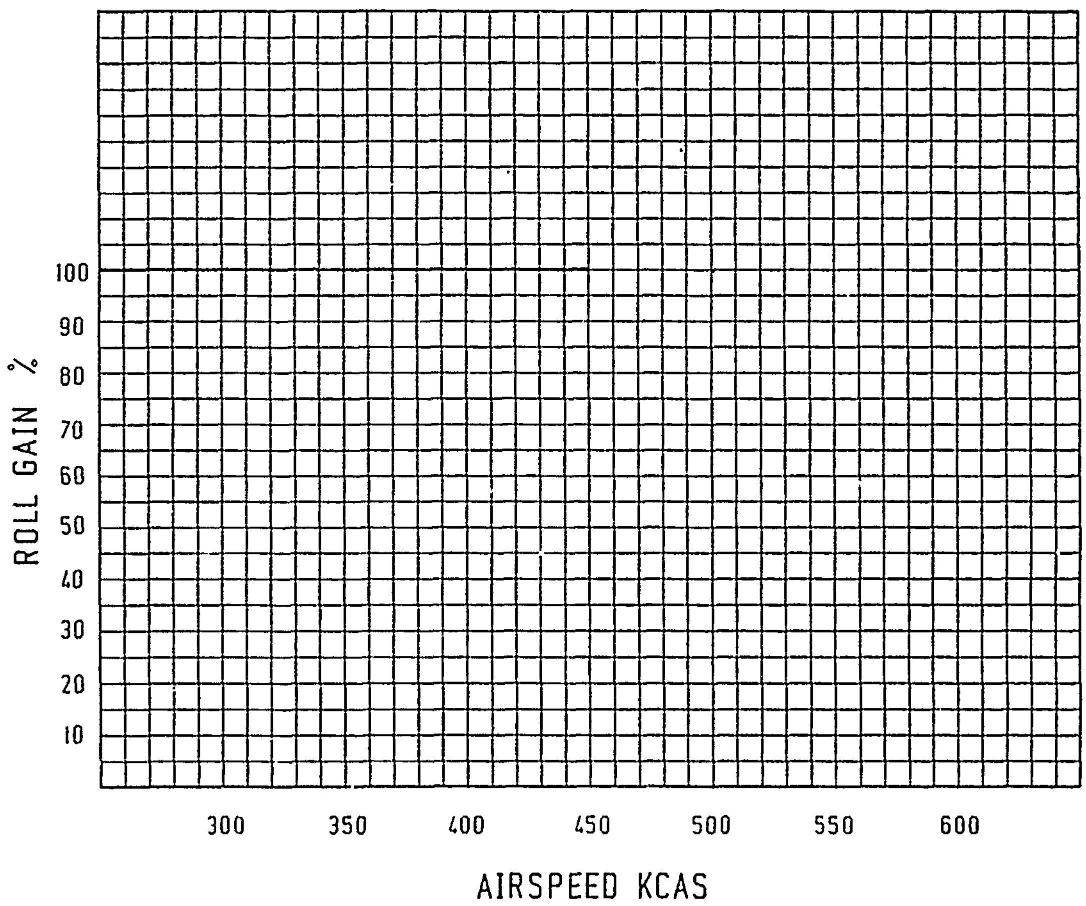
MANUAL ROLL GAIN LIMITS FOR HEIGHT OF 10,000 FT



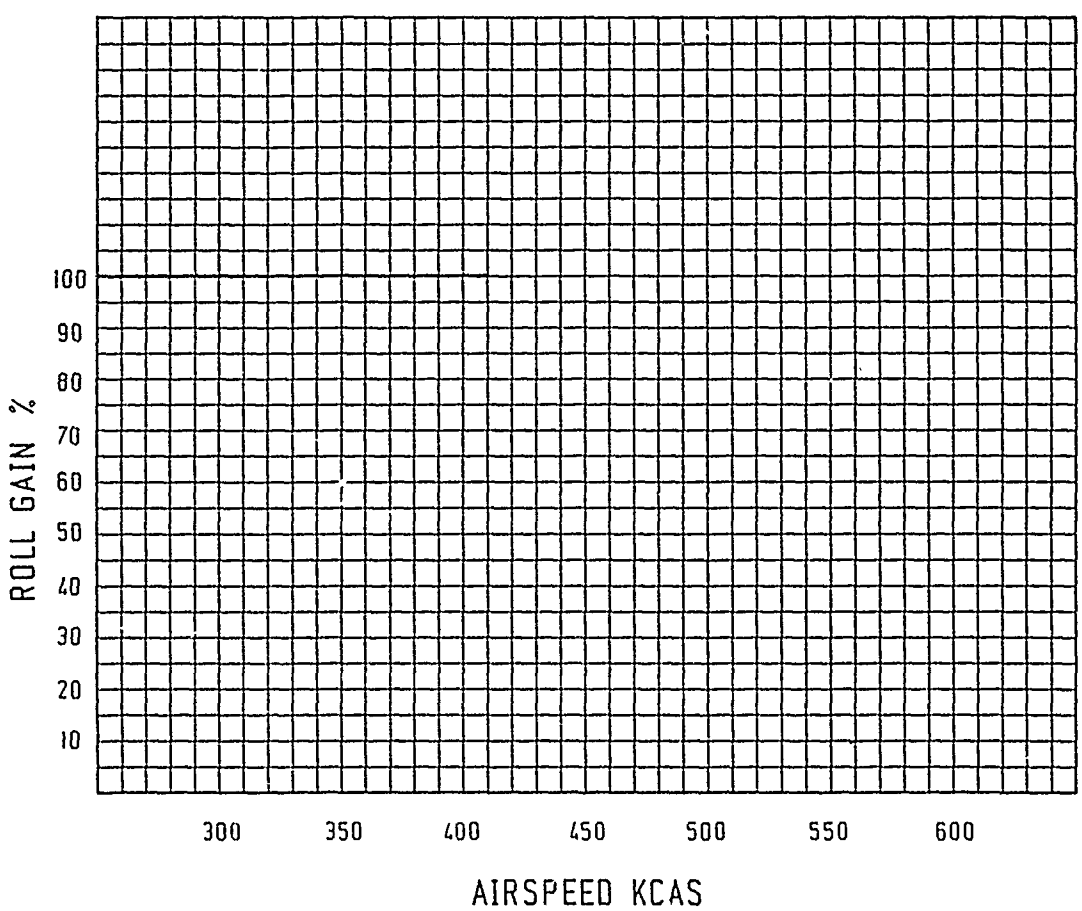
MANUAL ROLL GAIN LIMITS FOR HEIGHT OF 15,000 FT



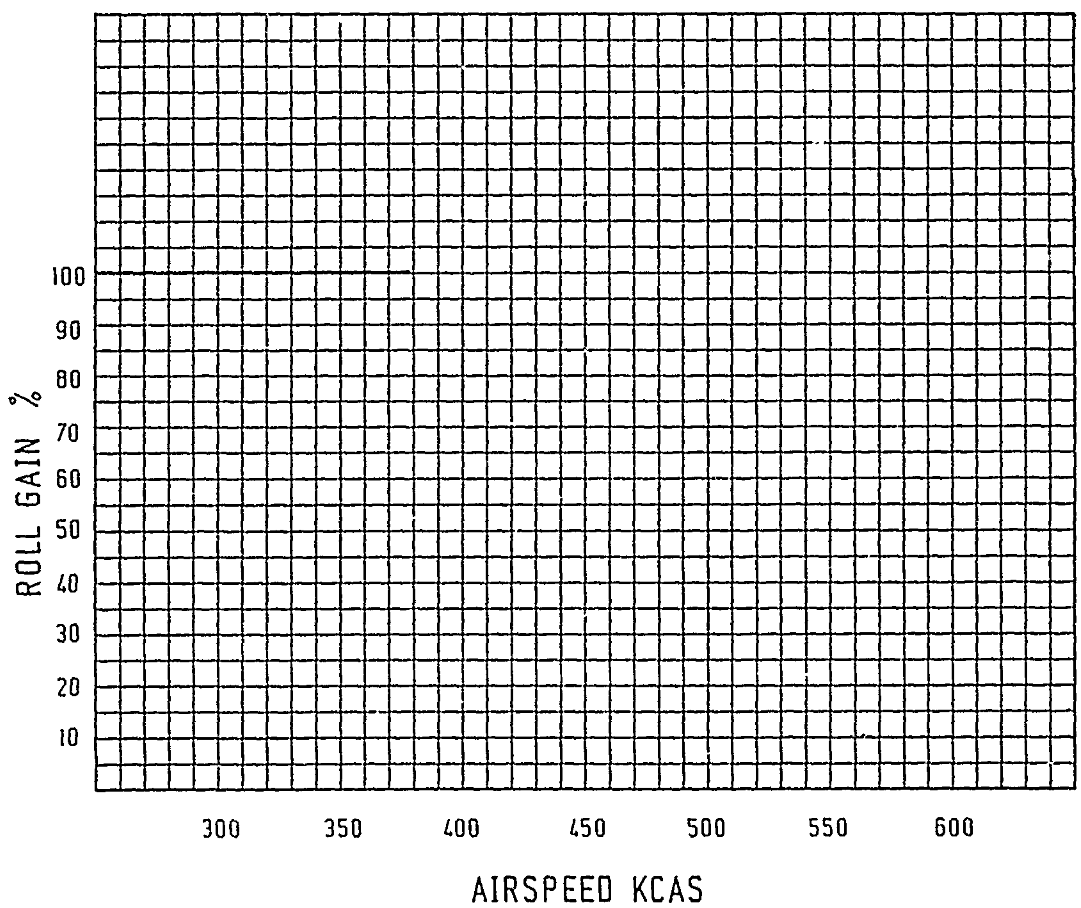
MANUAL ROLL GAIN LIMITS FOR HEIGHT OF 20,000 FT



MANUAL ROLL GAIN LIMITS FOR HEIGHT OF 25,000 FT



MANUAL ROLL GAIN LIMITS FOR HEIGHT OF 30,000 FT



AIRCRAFT RESEARCH AND DEVELOPMENT UNIT

TECHNICAL NOTE AERO NO 81

DETERMINATION OF THE PITCH AND ROLL GAIN LIMITS

FOR THE F-111C AUTOMATIC FLIGHT CONTROL SYSTEM

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